

**MWD**

METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

**Date:** May 27, 2003  
**To:** Principal Engineer A. Kirk Dimmitt  
**From:** Engineer John L. Scott  
**Subject:** Estimates of Tailwater Volumes in the Imperial Irrigation District

**SUMMARY**

As part of the technical assessments of water requirements of the Imperial Irrigation District (IID), Dr. James Rhoades developed several estimates of tailwater volumes occurring in IID (Rhoades 2003b). As you requested, I have compared Rhoades' tailwater volume estimates with other estimates I am aware of, both in terms of differences in estimating methodology and in terms of supporting data.

Rhoades (2003b) used several different methodologies for estimating tailwater: a water balance method, a chloride mass balance method for drainage at the IID service area level, a simple chloride mass balance method at the root zone level assuming irrigation water is the sole source of chloride, and a refined chloride mass balance method at the root zone level considering possible non-irrigation sources of chloride. Each independent approach yielded similar estimates of tailwater and deep percolation volumes, with Rhoades' tailwater volume estimates ranging from 617,000 to 669,000 acre-feet per year and deep percolation estimates ranging from 196,000 to 134,000 acre-feet per year.

There is a lack of tailwater flow data available to definitively quantify the volume of tailwater draining off farms served by IID.<sup>1</sup> However, several water balance studies have been conducted since the early 1980s by IID and its consultants, and by the Bureau of Reclamation (USBR) and its consultants and can be compared to Rhoades' recent estimates. In general, the several previous water balances diverge considerably on the relative amounts of tailwater and deep percolation that make up the total farm drainage. Studies prepared by IID and its consultants tend toward relatively high estimates of deep percolation and relatively low estimates of tailwater; whereas studies by the USBR as well as Rhoades tend toward relatively low estimates of deep percolation and relatively high estimates of tailwater.

In post-1985 water balances<sup>2</sup> prepared by IID and its consultants, tailwater volume was estimated by application of a presumed percent factor to the volume of water delivered to farms and deep

<sup>1</sup> In its Decision 1600 issued in 1984, the State Water Resources Control Board found that there was insufficient tailwater monitoring data available to estimate the volume of tailwater draining off farms served by IID.

<sup>2</sup> Water balances prepared for years prior to 1985 are not useful because they rely on poor quality flow data from IID's distribution and drainage system. Accordingly, they are not discussed as part of this memorandum.

percolation was considered to be the remaining farm drainage. The water balance prepared by the USBR consultants (Jensen (2002)) disagreed with that approach and instead presumed deep percolation was equal to the theoretical amount "needed for leaching" and tailwater was considered to be the remaining farm drainage. This is basically the same approach used in Rhoades (2003c) in projecting the tailwater volume under IID's revised order for 2003.

Annual tailwater volumes reported in Jensen (2002) varied from 430,893 to 764,221 acre-feet for the period 1987 through 2001 and averaged 22 percent of the volume delivered to farms. In comparison, tailwater volumes estimated by IID and its consultants within this period had little year-to-year variation in volumes and ranged from 15 percent to 17 percent of the volume delivered to farms. These water balance approaches incorporate a certain level of bias, in that they each depended on an indirect estimation of tailwater or deep percolation before the other is calculated by closure of the on-farm water balance.

Rhoades' utilized a chloride mass balance approach to estimate tailwater. Unlike the water balance approach, the chloride mass balance does not depend on a presumption of tailwater or deep percolation, but instead calculates these two volumes simultaneously. Rhoades used the average results from two different chloride mass balance approaches to conclude that the annual average tailwater from 1987 through 1998 was 637,400 acre-feet (or approximately 25 percent of the delivery to farms). The results of this independent analysis support his projected tailwater volume of 617,000 acre-feet estimated by water balance of the IID revised order and supports the conclusion of Jensen (2002) that tailwater is markedly higher (approximately 150,000 acre-feet and more) than that reported in post-1985 water balances prepared by IID and its consultants.

IID's previous direct estimate of deep percolation volumes that were based on tilewater<sup>3</sup> quantity and quality data available from 1975 to 1982 further supports the conclusion that its current estimate of tailwater is far too low. As reported in IID (1983) and Parsons (1985), this direct estimate of the deep percolation volume is approximately 280,000 acre-feet, which is significantly lower than that reported in post-1985 water balances prepared by IID and its consultants. This direct estimate, in turn, implies that tailwater, in fact, is much higher than what is currently being reported by IID and is more in line with the estimates of Rhoades and Jensen.

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<sup>3</sup> Most, but not all deep percolation water is collected by subsurface drains called "tile drains", which are a network of perforated pipes installed about 6 feet below land surface with an outlet to the surface drains via a sump pump or by gravity.

## BACKGROUND

The many and conflicting estimates of tailwater volumes occurring in IID stem from the lack of good data on actual tailwater flows. By way of background on this issue, the observations of the State Water Resources Control Board (SWRCB) in the early 1980s are still pertinent today.

In 1983, the SWRCB held hearings concerning allegations of misuse of water by IID.<sup>4</sup> At those hearings, the SWRCB was presented with several water balances of IID's irrigation and drainage system. SWRCB found that, while there was general agreement on the quantity of total water losses within IID, there was significant disparity in estimates of certain drainage components, including the volumes of tailwater and deep percolation draining from farms.

For example, in its investigation of water use by IID<sup>5</sup>, the Department of Water Resources (DWR) made special note that tailwater and "leach water"<sup>6</sup> are unmeasured, and therefore unknown, quantities. However, DWR estimated that tailwater was at least 15 percent of the water delivered to farms and could be as high as 22 percent of such water deliveries.<sup>7</sup>

As noted in Section 9.1 of its decision, Decision 1600, the SWRCB found that:

"Although there is general agreement on the quantity of total water losses within IID, there is considerable variation in the estimates of losses attributable to each of the four main sources described [tailwater, canal spills, canal seepage, and leachwater]. The difficulty in determining the quantity of loss from each source is due to the lack of measurements of canal spills and tailwater and problems in accurately estimating losses due to canal seepage and leachwater."

Accordingly, the SCRWB ordered IID to begin properly accounting for the volume of tailwater, tilewater, and other components of the water diverted from the Colorado River. More specifically, Decision 1600 required IID to:

"Develop and submit by February 1, 1985, a water accounting and monitoring procedure which will result in quantifying the following with reasonable accuracy: (1) actual deliveries to farmers' headgates, (2) tailwater, (3) canal spills, (4) canal seepage, and (5) leachwater. The water accounting procedure shall be capable of normalizing the data in order to make the information comparable from year to year. The District shall specify a schedule for implementing the water accounting procedure."

Unfortunately, IID has yet to implement the tailwater accounting and monitoring program that SWRCB ordered and, as such, there continues to be a lack of sufficient tailwater monitoring data for the District.

<sup>4</sup> "In the Matter of Alleged Waste and Unreasonable Use of Water by the Imperial Irrigation District"

<sup>5</sup> This study was conducted under California Water Code Section 275 and was completed in December 1981.

<sup>6</sup> Although they do not have the exact same meaning, "leach water", "deep percolation", and "tilewater" as used in this memorandum are synonymous.

<sup>7</sup> The volume of this uncertainty range estimated by DWR was 178,000 acre-feet and was graphically represented by DWR and is reproduced as Figure 1 to this memorandum. The uncertainty volume is either tailwater or tilewater.

## DISCUSSION

### Available Tailwater Monitoring Data

The amount of actual tailwater monitoring data available is fairly limited and consists of three principal sets.

First, as described in my May 27, 2003 memorandum to you,<sup>8</sup> in 1976 IID staff began actively monitoring tailwater in conjunction with enforcement of its 15-percent tailwater regulation.<sup>9</sup> In 1983 IID's enforcement of its tailwater regulation increased dramatically such that over 90 percent of the normal irrigations were monitored between 1983 and 1987. Thereafter, IID's enforcement of its 15-percent tailwater regulation declined to minimal, if any, enforcement. Monitoring data collected as part of these enforcement efforts have not been made available.

Second, from 1985 to 1990, IID staff also monitored tailwater for 7,489 irrigations during the course of an irrigation scheduling program (IID (1990)). As discussed in this memorandum, it is this small data set<sup>10</sup> that has been utilized by IID and its consultants to estimate current tailwater volumes within the District.

Third, tailwater monitoring data collected from 1996 to 2002 has recently been made publicly available by USBR (IID 1996-2002). The number of irrigations monitored each year ranged from 173 to 320 for a total of 1,693 of irrigation events that were considered to be of "good records" as noted on the data spreadsheets. Information recorded includes the date of the event, number of acres irrigated, delivery volume, tailwater volume, and (for 2000 through 2002 only) soil type. The actual farm monitored was not identified. In each year reported tailwater volumes measured as a percent of farm delivery ranged from below 5 percent to greater than 20 percent. The annual volume of water delivered to farms that were monitored by this effort ranged from 5,431 acre-feet to 9,461 acre-feet. In addition to the relatively few samples, the intent of the program in which this data was collected severely limits its usefulness in estimating tailwater volumes district-wide. This monitoring data was collected as part of the IID-Metropolitan Water Conservation Program and was shared with the growers participating in the program to serve as a tool for better managing irrigations. Thus, it should be expected that the relative tailwater volumes reported from this program would be lower than that occurring District-wide. To date there has been no analysis of this limited data to ascertain how the volumes observed actually relate to the actual District-wide tailwater volume.

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<sup>8</sup> Subject: "Net diversions by the Imperial Irrigation District with enforcement of its Tailwater Regulation."

<sup>9</sup> Imperial Irrigation District's *Rules And Regulations Governing The Distribution And Use Of Water*, Regulation No. 45

<sup>10</sup> As described in my May 15, 2003 memorandum on IID's enforcement of its tailwater regulation, there are more than 100,000 normal irrigation runs each year.

## Estimates Of Tailwater And Tilewater Volumes

In the absence of a full monitoring program and available data, Rhoades (2003b) used several different methodologies for estimating past tailwater volumes through a chloride mass balance. A chloride mass balance analysis is different from a water balance approach in that it does not depend on the prior estimate of tailwater volume in order to obtain a tilewater volume by closure, or vice-versa. Rhoades (2003b) concluded that the chloride mass balance approaches are reliable tools to help resolve the contrasting estimates of leaching being achieved in the IID and of the volumes of tailwater being discharged to the Salton Sea.

One of the chloride mass balance approaches used by Rhoades (2003b) was based on the approach used by Setmire *et al.* (1993) and Setmire *et al.* (1996) to estimate the contribution of subsurface drainage to the Alamo River. This "Setmire" approach utilizes the chloride concentration data of subsurface drainage based on water samples collected from tile drains, irrigation supply water based on samples collected from the East Highline Canal and the Colorado River above Imperial Dam, and blended surface and subsurface drainwater from samples collected from IID surface drains and the Alamo River. Rhoades also conducted two different chloride mass balances of the on-farm rootzone to estimate tailwater using (i) a simple approach assuming irrigation water is the sole source of chloride, and (ii) a refined approach that explored the effects of possible non-irrigation water sources of chloride to the root zone. Each independent approach yielded similar estimates of tailwater and deep percolation volumes, with Rhoades' tailwater volume estimates ranging from 618,000 to 669,000 acre-feet per year and respective deep percolation estimates ranging from 186,000 to 134,000 acre-feet per year. From these three approaches the "best estimate" of tailwater and tilewater volumes reported in Rhoades (2003b) indicate average annual volumes for the 1987-98 period was 637,400 acre-feet tailwater and 165,400 acre-feet tilewater. The resulting tailwater was 25.4 percent of that delivered to farms.

By water balance closure of the revised IID diversion of 3,100,000 acre-feet for calendar year 2003, Rhoades (2003c) projects a tailwater volume of 617,000 acre-feet. This projection assumes that the amount of deep percolation associated with the 15-percent tailwater condition calculated is at a practical maximum, and that the delivery of additional water to farms would only result in increased volumes of tailwater. The assumed limited ability of the soil to take in more water was corroborated by the results of the chloride mass balance analyses. As further support, an infiltration analysis by Rhoades (2003b) found that percolation rates estimated by the U.S. Geological Survey infer a tailwater volume of 668,000 acre-feet and deep percolation of 135,000 acre-feet.

To compare Rhoades' estimates with those by IID, its consultants, and other parties through various studies and using various indirect methods, I have reviewed twelve water balances produced since the early 1980s and their estimated volumes of tailwater and tilewater. These volumes and the method used to estimate them are reported in this memorandum. Table 1 presents a summarized description of each water balance, including a document citation, the agency sponsoring the balance, the calendar years considered, the method used and the volumes

estimated. The cited documents are listed in Attachment 1, which include specific quotes from the respective document describing the method followed in estimating volumes of tailwater and tilewater. Table 1 summarizes these estimates chronologically, with Rhoades' estimates appearing at the end.

### **Comparison of estimates**

#### Water Balances Prepared for Years Prior to 1985

Water balances prepared for years prior to 1985 (USBR (1984), IID (1983), and Parsons (1985)) were hampered by poor quality data concerning IID's operations, as noted in Decision 1600. This resulted in significant uncertainty in the estimates regarding farm drainage volumes. As noted by the SWRCB in Section 3.1 of its order WR 88-20, improvements have since been made by IID in measuring the volume of water delivered to farmers' headgates, delivered to lateral headgates, and spilled from canals. Thus, since 1985 there is little disagreement among the various estimates of overall farm drainage.

IID (1983) and Parsons (1985) water balances were unique in that they estimate tilewater directly. These studies made use of available quantity and quality data on tilewater that was compiled from 1975 to 1982. This data, combined with the inflow/outflow measurements, groundwater data, sump data, and areas and lengths of tile drains, were then used to develop an estimate of tilewater of approximately 280,000 acre-feet per year. The specific data and analysis that served as the basis of this tilewater estimate was not available for my review, and while the volume is higher than recently estimated by Rhoades, it is noteworthy that the tilewater volume is also much lower than as estimated by IID in subsequent years.

The water balance prepared by USBR (1984) estimated tailwater from data it collected in IID as part of its study from 1980 through 1983. The resulting estimate of tailwater was 324,000 acre-feet per year. The tilewater was assumed to be the residual of the on-farm balance, 236,000 acre-feet per year.

#### Water Balances Prepared by IID and its Consultants for Years After 1985

The water balances prepared by IID (1993) and IID (1994) assumed that tailwater equaled 15.6 percent of farm deliveries. This fixed percentage was based on IID tailwater studies reported in IID (1990), which admitted that the 15.6 percent value was "not statistically 'weighted' to reflect the actual crop percentages that exist in the District." Tilewater then was estimated as the residual of the on-farm water balance.

Boyle (1993) assumed a fixed percentage of 16.8 percent tailwater referenced to farm delivery based on the crop-weighted average of the data reported in IID (1990), with tilewater estimated as the residual of the on-farm water balance.

The WST (1998) water balance used tailwater volumes provided by IID staff having an annual average of 16.7 percent of the volume delivered to farms, which were equivalent to the volumes reported by Boyle (1993). The following passage from page A2-25 of WST (1998) comments on the quality of the tailwater volumes provided by IID:

"IID has made independent estimates of tailwater based on observations during the mid to late 1980s. This was a major undertaking and provided useful data for their purposes at the time. It provided estimates of the percentage of tailwater for some of the major crops and irrigation systems. By estimating the percentage of land in these various crop categories, IID has made estimates of the volume of tailwater. (For 1996, the 1995 tailwater volume was used, since a tailwater estimate was not provided and the volume delivered was approximately the same both years). IID currently does not record tailwater volumes, much of the data from those studies has been lost and use of those estimates would infer that no changes in practices and conditions have taken place. In addition, there are questions about the accuracy of flow measurements and whether the sites chosen were random. Given these limitations, estimates of tailwater volume are given a wide confidence interval." (emphasis added)

With respect to tilewater, WST (1998) estimated "excess deep percolation" for light-textured soils at 20% of the infiltrated water and gave it a wider confidence interval than that assigned to IID's tailwater estimates. The volume of the estimated "excess deep percolation" equates to the tailwater-tilewater uncertainty range estimated by DWR (1981).

IID (2002a) simply states, "Approximately 15 percent of the water applied to fields runs off as tailwater." No other information is provided to describe why 15 percent is an appropriate estimate. IID (2002b) is an attachment to IID (2002a) that describes the "Imperial Irrigation Decision Support System (IIDSS)," which is a model developed by IID of its irrigation and drainage system. The IIDSS model was used by IID to generate the water balances presented in IID (2002a). Estimated volume of tailwater in the calibrated model was 390,000 acre-feet, or 15.7 percent of farm delivery. However, the 1987-98 water balance presented in Figure 3.1-16 of IID (2002a) reported a lower value of tailwater and a higher value of tilewater, with the resulting tailwater volume being closer to the 15 percent volume limited by IID's Rules and Regulations.<sup>11</sup>

NRCE (2002) stated, "Tailwater is estimated to be 17 percent of headgate deliveries based on NRCE's field irrigation evaluations and IID data." This fixed percentage is very close to that used by Boyle (1993) and to the resulting tailwater percentage reported by WST (1998). Leaching volume was estimated by NRCE from its limited number of irrigation evaluations having a summer-season bias.<sup>12</sup> Similar to the WST (1998), NRCE quantified "remaining

<sup>11</sup> The reason for the discrepancy between IID (2002a) and IID (2002b) was not discussed in either document. Prior to the release of these documents, IID's PowerPoint presentation of the IIDSS model to staff of the U.S. Fish and Wildlife Service on April 20, 2001 included a slide of IID's water balance that reported a tailwater volume of 450,000 acre-feet, or 16.7 percent of farm deliveries.

<sup>12</sup> For a complete description of the bias in NRCE's field evaluations see the "Technical Review of a March 2002 Report Prepared by Natural Resources Consulting Engineers and entitled, *Assessment of Imperial Irrigation District's Water Use*" prepared by Metropolitan Technical Review Team and attached to the *Supplemental Declaration Of James D. Rhoades In Opposition To IID's Motion For Preliminary Injunction* dated March 6, 2002.

tilewater" that was "not used for leaching," setting this value equal to the residual of its on-farm water balance. As discussed in more detail in my May 27 memorandum to you,<sup>13</sup> NRCE's assertion that additional 138,000 acre-feet of water is applied annually for reclamation leaching in-between crops is poorly supported, and that IID reports such reclamation leaching actually practiced in the IID water service area amounts to approximately 16,000 acre-feet per year. Based on this IID data, approximately 112,000 acre-feet of water that NRCE claimed was used for reclamation leaching was discharged to drains in some other fashion. Assuming this volume was actually discharged as tailwater, the total NRCE tailwater volume would be 548,000 acre-feet, or 21.9 percent of the volume delivered to farms, which is similar to that reported in Jensen (2002). This additional volume equates to the tailwater-tilewater uncertainty range estimated by DWR (1981).

In sum, the common approach in the above series of estimates is to first establish the tailwater fraction, and then calculate the tilewater volume as the residual amount. However, the basis for choosing the appropriate initial tailwater fraction is not supported. The initial tailwater fraction is either based on limited studies, some of which where the underlying data has been lost, or is merely assumed. The assumed initial tailwater fractions are consistently low which, when compared to Rhoades' estimates, result in relatively low tailwater volumes and relatively high tilewater volumes.

#### Water Balances Prepared by USBR Consultants (Jensen (2002))

In partitioning the volumes of tailwater and tilewater, Jensen (2002) noted that use of tilewater as the residual term does not account for the relatively large variation in annual tailwater. The amount of water infiltrating the soil is limited by soil characteristics. Thus, depending on permeability, some soils will permit higher infiltration rates than others. Nevertheless, the infiltration rate of all soils is limited to an upper bound. In contrast, the only limit on tailwater is the management of the applied water by the irrigator. The volume of tailwater is governed by the volume of water applied that is in excess of the infiltration rate of the soil. A comparison of the limited nature of soil infiltration to the relative infinite capacity to convey excess applied water through the tailwater box suggests that tailwater volumes would be significantly more variable than tilewater on a year-to-year basis.

Accordingly, Jensen (2002) first estimated tilewater as the amount "needed for leaching," which was based on the application of a constant (0.124) to the estimated amount of crop ET met by irrigation water, with an annual adjustment made for the salinity of Colorado River. Estimated tailwater was assumed to be the residual of the on-farm water balance and, on an annual basis, ranged from 18 percent (501,081 acre-feet) of the volume delivered to the farm to 29 percent (764,221 acre-feet). As estimated by Jensen (2002), the annual average tailwater volume for 1987 through 2001 was 556,596 acre-feet, or 22.0 percent of the volume delivered to farms.

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<sup>13</sup> Subject: "Previous estimates of Imperial Irrigation District net diversion requirements"

Rhoades also estimated tailwater and tilewater using a similar methodology. (These estimates were in addition to his estimates using the chloride mass balance methods.) From his on-farm water duty calculations, Rhoades calculated the resulting net diversion requirement by adding his estimate of deliveries to duck ponds and fish farms and IID's estimated volumes of conveyance and distribution system losses and miscellaneous deliveries upstream of the farm headgates. Table 15 from Rhoades (2003c) shows that with IID's revised order at 3.1 million acre-feet in total diversions for 2003, tailwater volume is projected to be approximately 617,000 acre-feet, or about 24.5 percent of farm deliveries. This method assumes that the volume of tilewater is physically limited, as does Jensen's method. Rhoades' projected tilewater volume from this approach is about 197,000 acre-feet, which is the amount required for leaching plus an additional allowance for distribution non-uniformity.

## CONCLUSIONS

### Estimates Based on Presumed Tailwater Volumes as a Percentage of Deliveries to Farms

Tailwater volumes determined through a water balance analysis and a presumed fixed percentage of tailwater is the least reliable of the methods discussed herein. As noted in Jensen (2002), "Use of the crop-leaching component in the closure term does not reflect the relatively large variation in annual tailwater." Because tailwater is much more sensitive to variations in on-farm water management, tailwater volumes can be expected to vary much more than tilewater volumes from year-to-year. Therefore, assuming a fixed percentage is not definitive.

As a result, tailwater volumes estimated by this approach (IID (1993), Boyle (1993), IID (1994), IID (2002a), IID (2002b), and NRCE (2002)) are, as a direct result of the percentage assumed, consistently low. And the poorly documented and limited dataset used by IID as a basis for the presumed tailwater percentage renders these estimates suspect.

Although WST (1998) did not presume a fixed percentage for each year it analyzed, it made use of tailwater volumes estimated by IID staff that were consistent with the limited tailwater data reported in IID (1990). Annual tailwater volumes reported in WST (1998) ranged from 15.9 percent to 17.1 percent of the volume delivered to farms and were "given a wide confidence interval."

#### Estimates Based on Direct Estimation of Tilewater or Tailwater Volumes

Tailwater and tilewater volumes estimated directly from field data are more reliable than those based solely on a presumed tailwater percentage.

In that regard, IID (1983) and Parsons (1985) water balances were unique in that they estimated tilewater directly. These studies made use of available quantity and quality data on tilewater that was compiled from 1975 to 1982, with a resulting tilewater estimate of approximately 280,000 acre-feet per year. With the exception of Boyle (1993), this direct estimate of annual tilewater volumes is significantly less than that estimated through a presumed tailwater percentage approach. This direct estimate is approximately 50,000 acre-feet less than that estimated by NRCE (2002) and 100,000 to 150,000 acre-feet less than that estimated by IID (1994), WST (1998), IID (2002a), or IID (2002b). This implies that tailwater was underestimated in those IID studies.

#### Estimates Based on Presumed Tilewater

Both Jensen (2002) and Rhoades (2003c) used approaches similar to the other water balance approaches, except that they first estimated tilewater based on calculated leaching requirements. The highest estimated tailwater volume was reported by Jensen (2002) with this approach, but with tailwater volumes varying from year-to-year, with an annual average tailwater volume of 22.0 percent of that delivered to farms. Rhoades (2003c) projected a year 2003 tailwater volume of 24.5 percent using this approach.

#### Estimates Based on Chloride Mass Balance

The results of several independent chloride mass balance analyses reported in Rhoades (2003b) indicate that the annual average tailwater volumes were 25.4 percent. The actual estimates using different chloride mass balance approaches were very similar to each other and to Rhoades' estimated tailwater by water balance. Because the chloride mass approach does not depend on a initial estimation of tailwater or tilewater to calculate the other volume, a chloride mass balance analysis is free of the bias that may be inherent in judgments incorporated into the water balance approaches. One might expect that IID's estimates are biased toward underestimating tailwater volumes, in order to counter any accusations of waste similar to that made by the SWRCB. Similarly, the assertion contained in Jensen (2002) that tilewater is equal to the "amount needed for leaching" and similar assertions by Rhoades (2003a) could be argued as biased toward overestimating tailwater. However, the unbiased results of the chloride mass balance indicate that actual tailwater volumes are significantly greater than that estimated by IID and its consultants, and very similar to that estimated by Jensen (2002) and Rhoades using their water balance approach. This suggests that the assertions by Jensen and Rhoades that the amount of water infiltrating the soil is limited by soil characteristics are valid.

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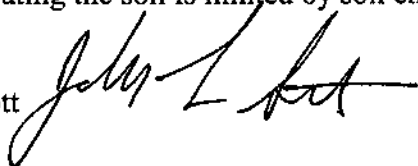
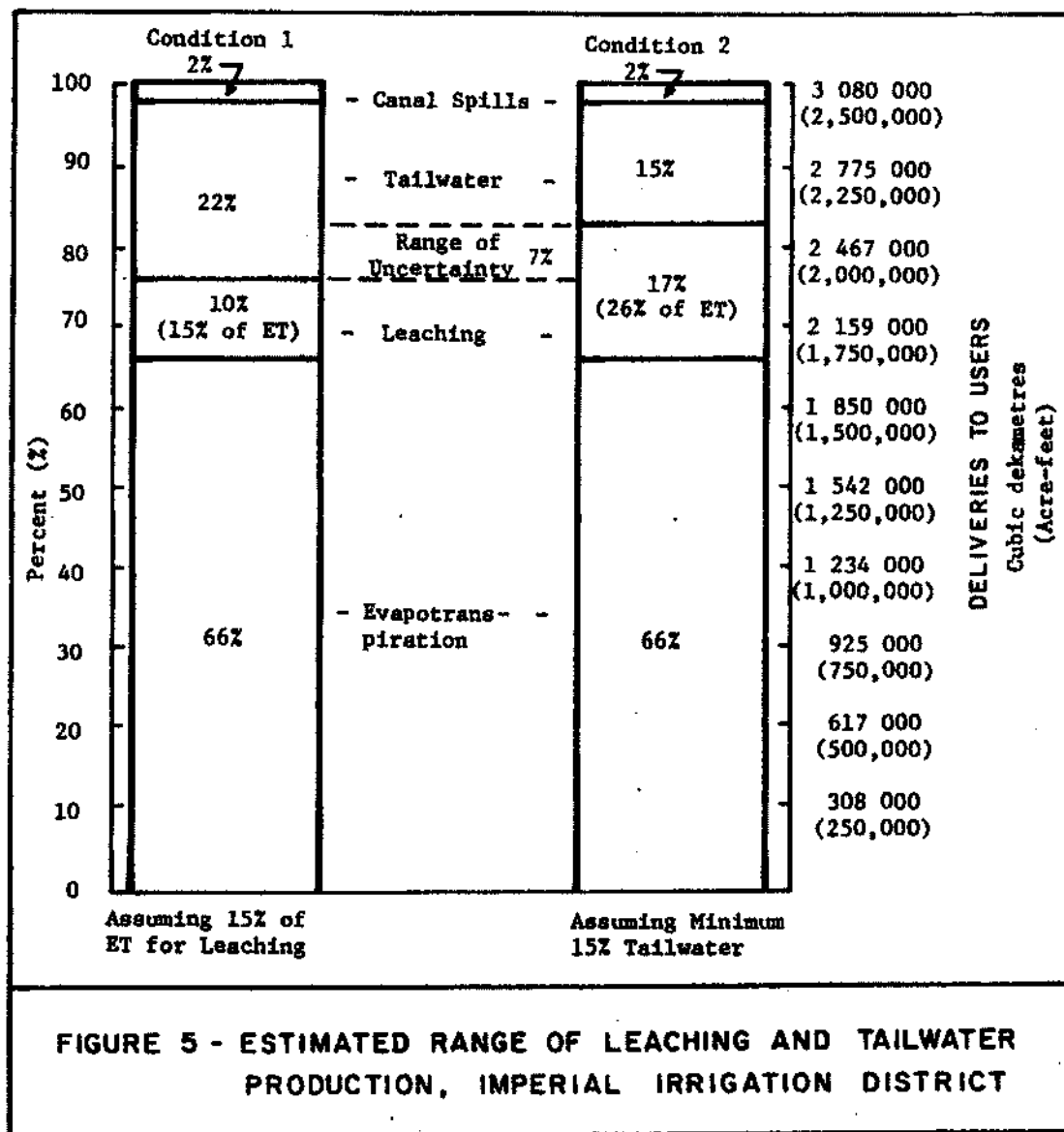


Figure 1. Tailwater-tilewater uncertainty range estimated by DWR (1981).



**Table 1.** Summary of water balances estimating volumes of tailwater and tilewater.

(volumes in thousand acre-feet)

Document citation	Agency causing the balance to be prepared	Calendar years considered	Method used to estimate tilewater and tailwater volumes	Delivery to farms volume	Tilewater volume (percent of delivery)	Tailwater volume (percent of delivery)
IID 1983	IID	1977 through 1979	Tilewater estimated from the average of four methods that included a salt mass balance of IID drainage and volume calculation based on tile drainage and miles of tile drainages compared to contributions to tile drainage, tailwater equal to residual.	2,329	281 (12.1%)	312 (13.4%)
USBR 1994	USBR	1977 through 1980	Tailwater estimated from data collected after 1980, tilewater equal to residual.	2,360	236 (10.0%)	324 (13.7%)
Parsons 1985	IID	1982 through 1984	Assumed tilewater averages 280 kaf based on IID (1983) analysis and is proportional to consumptive use, tailwater equal to residual.	2,147	280 (13.0%)	211 (9.8%)
IID 1993	IID	1987 through 1991	Assumed tailwater is 15.6 percent of the water delivered to farms based on the simple average of limited sample data collected by IID, tilewater equal to IID drainage system balance residual.	2,552	312 (12.2%)	398 (15.6%)
Boyle 1993	IID	1987 through 1992	Assumed tailwater is 16.8 percent of the water delivered to farms based on the crop-weighted average of limited sample data collected by IID, tilewater equal residual.	2,426	276 (11.4%)	407 (16.8%)

**Table 1.** Summary of water balances estimating volumes of tailwater and tilewater. (continued)

(volumes in thousand acre-feet)

Document citation	Agency causing the balance to be prepared	Calendar years considered	Method used to estimate tilewater and tailwater volumes	Delivery to farms volume	Tilewater volume (percent of delivery)	Tailwater volume (percent of delivery)
IID 1994	IID	1987 through 1991	Assumed tailwater is 15.6 percent of the water delivered to farms based on the simple average of limited sample data collected by IID, tilewater equal to IID drainage system balance residual assuming 98 percent of canal seepage goes to subsurface storage.	2,552	432 (16.9%)	398 (15.6%)
WST 1998	IID	1987 through 1996	Tailwater volume provided by IID staff. Tilewater determined as the sum of independent estimates of beneficial leaching and of excess deep percolation.	2,474	425 (17.2%)	414 (16.7%)
IID 2002a	IID	1987 through 1998	Assumed that approximately 15 percent of the water delivered to farms runs off as tailwater, tilewater equal to residual.	2,508	417 (16.6%)	386 (15.4%)
IID 2002b	IID	1987 through 1998	Used finite element model to partition tailwater and tilewater at each field based on soil texture, crop, irrigation method, and volume of water delivered in excess of crop demand (calculation and data not documented).	2,490	394 (15.8%)	390 (15.7%)

**Table 1.** Summary of water balances estimating volumes of tailwater and tilewater. (continued)

(volumes in thousand acre-feet)

Document citation	Agency causing the balance to be prepared	Calendar years considered	Method used to estimate tilewater and tailwater volumes	Delivery to farms volume	Tilewater volume (percent of delivery)	Tailwater volume (percent of delivery)
NRCE 2002	IID	1988 through 1997	Tailwater estimated to be 17 percent of headgate deliveries based on NRCE's irrigation evaluations of 9 fields and limited IID tailwater data. Tilewater equal to residual with estimation of the reclamation leaching requirement.	2,503	331 (13.2%)	426 (17%)
Jensen 2002†	USBR	1987 through 1993	Tilewater calculated as $(0.124) \times$ (adjustment factor for Colorado River salinity) $\times$ (irrigation water consumed on agricultural land). Tailwater equal to residual.	2,413	199 (8.3%)	523 (21.7%)
Jensen 2002†	USBR	1994 through 2001	Tilewater calculated as $(0.124) \times$ (adjustment factor for Colorado River salinity) $\times$ (irrigation water consumed on agricultural land). Tailwater equal to residual.	2,643	202 (7.7%)	586 (22.2%)

†The results from Jensen 2002 are split to separate out the post 1993 period of sustained high diversions by IID.

Table 1. Summary of water balances estimating volumes of tailwater and tilewater. (continued)

(volumes in thousand acre-feet)

Document citation	Agency causing the balance to be prepared	Calendar years considered	Method used to estimate tilewater and tailwater volumes	Delivery to farms volume	Tilewater volume (percent of delivery)	Tailwater volume (percent of delivery)
Rhoades 2003c	Metropolitan	2003	Tilewater calculated using WATSUIT computer model, including allowance for excess deep percolation, for the 15-percent tailwater condition. Tailwater projected to equal the sum of the volume calculated under the 15-percent condition plus the additional net diversion associated with the revised order for 2003.	2,519	197 (6.8%)	617 (24.5%)
Rhoades 2003b	Metropolitan	1987 through 1998	Tilewater and tailwater determined by chloride mass balance using the "Setmire approach" applied to IID's average annual drainage system water balance.	2,508	185 (7.4%)	618 (24.6%)
Rhoades 2003b	Metropolitan	1987 through 1998	Tilewater and tailwater determined by chloride mass balance of the root zone assuming irrigation water is the sole source of chloride (approach 1).	2,508	146 (5.8%)	657 (26.2%)
Rhoades 2003b	Metropolitan	1987 through 1998	Tilewater and tailwater determined by chloride mass balance of the root zone considering the potential for non-irrigation water sources of chloride (approach 2).	2,508	134 (5.3%)	669 (26.7%)
Rhoades 2003b	Metropolitan	1987 through 1998	"my best estimate of tailwater volume for the IID service based on chloride balance considerations"	2508	165 (6.6%)	637 (25.4%)

## References

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Setmire, J.G., Schroeder, R.A., Densmore, J.N., Goodbred, S.L., Audet, D.J., and Radke, W.R.; 1993; *Detailed Study Of Water Quality, Bottom Sediment, And Biota Associated With Irrigation Drainage In The Salton Sea Area, California, 1988-90*; U.S. Geological Survey Water Resources Investigation Report 93-4014

U.S. Bureau of Reclamation; July 1984; *Water Conservation Opportunities: Imperial Irrigation District, California*

Water Study Team (WST); March 1998; *Imperial Irrigation District Water Use Assessment For the years 1987-1996*; prepared for the Imperial Irrigation District

**Department of Water Resources; December 1981; *Investigation Under California Water Code Section 275 of Use of Water By Imperial Irrigation District***

"Almost all farms produce tailwater. The quantities produced range from smaller to greater than 15 percent. Because tailwater and leach water are unknown quantities, it is believed that tailwater is at least 15 percent of the total delivery [380,000 acre-feet] annually, as shown graphically in Figure 5 (condition 2). Tailwater could be as much as 22 percent of the total delivery, or [558,000 acre-feet], if it is assumed that leach water is 15 percent of evapotranspiration--ET (Figure 5, condition 1)." (page 28)

"Calculations made for this report indicate that the average leach water application in the Valley may be considerably higher than is generally thought. Unfortunately, leachwater and tailwater cannot be separated because no reliable data are available." (page 43)

**Imperial Irrigation District Exhibit 16 to the State Water Resources Control Board in the Matter of Alleged Waste and Unreasonable Use of Water by the Imperial Irrigation District submitted December 12, 1983**

"We then calculated or estimated the amount of leaching within the Imperial Irrigation District and we did this using all of the available information and estimating by some four methods what this leach water component might be and we then compared the inflow, the quantity of the inflow from the All-American Canal to the quality of the leach water to define a quantity of leach water. We utilized sumps in the same way.

"We compared the quality of the leach water also to the New and Alamo Rivers and then we utilized tile drainage and miles of tile drainages compared to contributions to tile drainage from the various sources and then extrapolated to obtain consumptive use, and these were from various values for the period 1974 through 1982.

"The resulting average of that was 281,000 acre-feet per year. So, we then developed the remaining quantity as to tailwater of 312,000 acre-feet." (Testimony of Doug Welch of IID)

**U.S. Bureau of Reclamation; July 1984; *Water Conservation Opportunities: Imperial Irrigation District, California***

"The break down between 'deep percolation and leaching' and 'tailwater spills' is estimated. The tailwater is representative of data collected during the study."

**Parsons Water Resources, Inc.; 1985; *Water Requirements and Availability Study for Imperial Irrigation District***

"...leach water averages 280,000 AF and is proportional to consumptive use in Table 5-1; tailwater is residual amount." (footnote "e" to Table 5-6 on page 5-16)

\* \* \*

"Although no Districtwide [sic] measurements are available, a significant amount of quantity and quality data on leach water has been compiled, particularly from 1975 to 1982. This data, combined with the inflow/outflow measurements, groundwater data, sump data, and areas and lengths of tile drains, was used to develop estimates of leach water from the District.

"Four methods were used to arrive at the annual quantity of leach water:

<u>"Methods of Leach Water Calculation</u>	<u>AF</u>
"Comparison of salinity of tile drainage to salinity of supply water (1981)	266,000
"Comparison of salinity of tile drainage to in New and Alamo Rivers (1981)	280,000
"Comparison of quality of sump salinity to salinity of supply water (1975-1982)	267,000
"Comparison of sump discharge to land area served and tile drainage (1974-1982)	311,000
"Average	281,000"

"These estimates are believed to represent the actual practice from about 1975 to 1982 under the climatic cropping [sic] and water supply conditions that prevailed during that period. The amount of leach water from year to year would vary depending on these factors. However, based on the foregoing analyses, coupled with the water balance conditions presented in Table 5-6, the estimate of average annual leach water is 280,000 AF/year." (pages 5-17 and 5-18)

***Imperial Irrigation District; 1993; Draft Environmental Impact Report for Modified East lowline and Trifolium Interceptors, and Completion Projects***

"On-farm tailwater (N) is based on a study performed by IID that showed irrigation tailwater to be roughly 15.6 percent of the water delivered to the farm. Of all the components of the total discharge to the Salton Sea, tile water resulting from irrigation deep percolation (O) is the hardest to measure directly because tile drain flows typically include other subsurface flows. Therefore, this component is estimated using the following equation:

$$"O = (G+H+I) - (C+D+F+J+K+L+M+N).$$

"The constituent concentration multiplier in Table E-1 is the factor by which a given concentration of a conservative constituent (e.g., TDS) in irrigation water is increased as it passes through the soil profile and exits in tile water. The multiplier is calculated as the sum of farm consumptive use and tile water divided by tile water. For instance, an irrigation event that results in 15.6 percent tailwater and 12.2 percent tile water has a consumptive use, including evaporation, of 72.2 percent. Thus, 84.4 (12.2 + 72.2) percent of the water applied to the field

contributes to the loading of dissolved constituents. These soluble constituents are typically flushed out of the soil profile by waters percolating beyond the crop root zone and captured by a tile drain system. The average concentration of most constituents in irrigation tile water (assuming no other subsurface flows are intercepted) is expected to be 84.4/12.2 or 6.9 times greater than the original concentration in irrigation water." (Appendix E, pages E-3, E-4)

**Boyle Engineering Corporation; August 1993; *On-farm Irrigation Efficiency: Special Technical Report for Imperial Irrigation District***

**"6.5.4 Tailwater Discharged to Drains**

"There are two components of tailwater. These are (1) agricultural tailwater and (2) discharges from M&I water users. The detailed calculations are included in the Appendix B. Agricultural Tailwater was estimated by evaluating the data collected as part of the on-farm water conservation program conducted in the 1980's by IID. The program generated a database which includes a 7,000 plus record of irrigation events in IID. This program was jointly funded by IID and the USBR. The database includes measurements of delivered water, tailwater, and in some cases the tilewater. Data was collected to reflect the crop mix at the time of the investigations. The results of the tailwater study have previously been reported by IID as an average of the number of tailwater samples. The reported tailwater percentage from the program was 15.6% of the delivered agricultural water. This report utilized the results of the database to weight the tailwater by the crop mix during the years 1987 through 1992 ... The detailed spreadsheet analysis is included in Appendix B. The results of the analysis indicated that the tailwater percentage used for this report averaged about 16.8% of the delivered water. Table 6-29 is a summary of the estimated agricultural tailwater in IID."

**Imperial Irrigation District; May 1994; *Final Environmental Impact Report for Modified East lowline and Trifolium Interceptors, and Completion Projects***

"'On-farm tailwater' (Code N) is estimated as roughly 15.6 percent of the water delivered to users (Code B). This percentage is based on a study performed by IID in 1990. 'On-farm irrigation tile flow' (Code O) is perhaps the hardest to measure or estimate because tile drain flows typically include other subsurface flows. Therefore, this component is estimated as a closure term for the 'output side' of the water balance using the following equation:

$$"O = (G+H+I) - (C+0.02D+F+J+K+L+M+N)$$

"The tile flow concentration multiplier in Table E-1 (i.e., 4.9) is the factor by which a given concentration of a conservative constituent (e.g., TDS) in irrigation water is increased by waters percolating beyond the crop root zone and being captured by the tile drain system. The multiplier is calculated using the following mass-balance relationship: applied water (100 percent) times a concentration of 1 (original concentration) equals tailwater (15.6 percent) times its concentration of 1.1 (Table E-2) plus tile flow (16.9 percent) times the unknown concentration. Solving for the unknown, the average concentration of irrigation leachate in tile water (assuming no other subsurface flows are intercepted) is expected to be (100 - 17.2)/16.9 or 4.9 times greater than the original concentration in the irrigation water." (Appendix E, page E-4)

**Water Study Team (WST); March 1998; *Imperial Irrigation District Water Use Assessment for the Years 1987-1996*; prepared for the Imperial Irrigation District**

"In an earlier section, we determined the amount of irrigation water that is consumed on agricultural land (Table A2-15). The remaining water (delivered less consumed) must enter the drainage system as either tailwater or deep-percolation that is intercepted by the drainage system, again assuming no storage changes. These volumes are shown in Table A2-23, which is based on the measured deliveries. One could also estimate the volume entering the drainage system based on the canal inflow, but as shown in Table A2-21 these are in close agreement and would not change the estimated volumes significantly.

"IID has made independent estimates of tailwater based on observations during the mid to late 1980s. This was a major undertaking and provided useful data for their purposes at the time. It provided estimates of the percentage of tailwater for some of the major crops and irrigation systems. By estimating the percentage of land in these various crop categories, IID has made estimates of the volume of tailwater. (For 1996, the 1995 tailwater volume was used, since a tailwater estimate was not provided and the volume delivered was approximately the same both years). IID currently does not record tailwater volumes, much of the data from those studies has been lost and use of those estimates would infer that no changes in practices and conditions have taken place. In addition, there are questions about the accuracy of flow measurements and whether the sites chosen were random. Given these limitations, estimates of tailwater volume are given a wide confidence interval."

\* \* \*

"In Appendix 4, the amount of water that can be considered beneficial leaching for salinity control has been determined. For the very heavy soils, leaching volume was estimated based on the measured field soil salinity values and relative length of tile drainage lines. Since soil salinity values are higher than threshold salinity values for most crops, all of the deep percolation water is assumed to be beneficial. These very heavy soils represent approximate half of the irrigated area (Imperial plus part of Holtville soils), and we assumed they represent half of the crop ET. The data on crop mix are not correlated with the data on soil types, so it is difficult to estimate which soils have which crops and thus what quantity of ET should be attributed to which leaching fraction. So we simply assigned the ET to each soil type proportional to area.

"For the light and medium textured soils, beneficial leaching was computed from an assumed threshold electrical conductivity value of 1.7 dS/m, since measured field soil salinity values suggest that adequate leaching is taking place for those soils. However, some excess deep percolation is probably occurring on the light-textured soils. These soil represent approximately one quarter of the irrigated area (Antho, Indio, Meloland, Niland, Rositas soils). We assume for the light-textured soils that 20% of the infiltrated water is excess deep percolation (e.g., from a combination of nonuniformity and over application). The remaining quarter of the area are medium soils (Glenbar and most of Holtville soils), which we assume also have adequate leaching, but no extra deep percolation.

"A comparison of water entering the drainage system from agricultural land in the IID study area computed from measured, recorded deliveries minus water-balance-based consumption (Table A2-23) and from independent estimates of tailwater and deep percolation are shown Table A2-24. The differences between these two estimates, not considering measurement error, are errors in tailwater and deep percolation estimates. If we had used the recorded volumes delivered, the water delivered minus consumed would have averaged 730,000 ac ft, making the average error in the farm system water balance -4.3% rather than -1.0%."(pages A2-25 through A2-26)

**Imperial Irrigation District; June 2002a; *Imperial Irrigation District Water Conservation and Transfer Project Final Environmental Impact Report/Environmental Impact Statement* (State Clearinghouse No. 99091142)**

"Approximately 15 percent of the water applied to fields runs off as tailwater. Except in fields with tailwater recovery systems (TRSSs), this water is no longer available for on-farm use and is discharged into either the drainage system or rivers within the IID water service area. Irrigation water that percolates through the soil into the drainage system is collected by subsurface tile drains and, to a lesser extent, by surface drains. The open drains (mostly the lateral drains) collect tailwater and tilewater from farms as well as operational discharge and canal seepage water emanating from IID's delivery system."

**Imperial Irrigation District; June 2002b; *Imperial Irrigation District Water Conservation and Transfer Project Final Environmental Impact Report/Environmental Impact Statement* (State Clearinghouse No. 99091142), Attachment I**

#### "I.2.3 On-farm Modeling

"On-farm data included information on crop acreage, crop type, and irrigation method, soil type, and name of delivery turnout. Crop water consumption was estimated by applying established estimation methods to crops recorded at each parcel receiving water deliveries. Evaporation at each parcel was also estimated using established practices based on the soil texture, method, and frequency of irrigation recorded at each parcel. Water not consumed by crops or evaporated from fields was partitioned between tailwater and tilewater at each field based on soil texture, crop, irrigation method, and volume of water delivered in excess of crop demand."  
(Attachment I, page I-5)

**Natural Resources Consulting Engineers, Inc.; March 2002; *Assessment of Imperial Irrigation District's Water Use***

"The analysis presented in Tables IV-9 and IV-10 used the following assumptions and information:

"Table IV-9 assumptions and analysis:

- "• The average annual net cropped area is 462,000 acres.

- “• 13% of the net cropped area has light soils with permeability greater than 0.2 inches per hour throughout the top four feet based on the Soil Conservation Service (SCS) Soil Survey.
  - “• The other deep percolation for light soils is an assumption based on typical irrigation uniformity.
  - “• The average leaching requirement of the light soil is estimated to be 7 inches per year. This estimate is 10-7% of headgate deliveries based on the leaching fraction.
  - “• 87% of the net cropped area has medium and heavy soils in the top four feet, which limit permeability to less than 0.2 inches per hour based on the SCS Soil Survey.
  - “• The leaching of the heavy soil is based on NRCE's field irrigation evaluations during which about 0.2 inches of leaching occurred per irrigation during the cropping period, as well as an estimated irrigation leaching of 5.8 inches during a typical leaching irrigation.
  - “• Thirty-two percent of the heavy soil area is in alfalfa, six percent in Bermuda grass, and 62 percent is other crops. The crops are irrigated 16, 14, and 12 times per year, for alfalfa, Bermuda grass, and other crops, respectively. The number of irrigations were obtained from IID irrigation delivery records and are very similar to those used in crop production budgets developed by the University of California (UC, 1996). For example, the average annual deep percolation during the crop irrigation is 3.2 inches (0.2 in/irrigation x 16 irrigations).
  - “• The leaching irrigation on heavy soils occurs once each year for annually or multiple cropped acreage, once every four years for alfalfa, and once every five years for Bermuda grass. For example, the average annual deep percolation for alfalfa is 1.45 inches (5.8 inches per leaching/4 years between leaching).
  - “• The annual average (1988-1997) headgate deliveries are 2,503,000 acre-feet and the average annual on-farm irrigation consumptive use is 1,746,000 acre-feet.
- “Table TV-10 assumptions and analysis:
- “• Tailwater is estimated to be 17 percent of headgate deliveries based on NRCE's field irrigation evaluations and IID data.
  - “• Tailwater used for horizontal leaching of heavy soils (87% of the net cropped area) is estimated at 3.4 percent of headgate deliveries, as previously described.
  - “• Other deep percolation on medium and heavy soils is equal to total deliveries minus on-farm consumptive use minus tailwater minus leaching deep percolation on medium and heavy soils, minus leaching deep percolation on light soils minus other deep percolation on light soils. This value is  $(2,503-1,746-426-228-35-35=33 \text{ kaf})$ . The 33 kaf/year is equivalent to 0.98 in/year on the heavy soils.” (pages IV-28 and IV-29)

**Jensen, Marvin E., Walter, Ivan A.; November 2002; *Assessment Of 1997-2001 Water Use By The Imperial Irrigation District***

**"4.6 Leaching Requirements (LR)**

"Many studies have been conducted on the soil salinity problems encountered in the IID. The most recent analysis is the special report prepared by Rhoades (2002). Rhoades simulated typical six-year crop rotation of alfalfa, wheat and lettuce and computed the leaching requirements by several different methods and models, including the traditional LR equation published in 1976 that has been used in several other recent reports. Rhoades reported that the volume of leaching water when referenced to the water infiltrated to be 0.124 when using the traditional method of calculating the LR. Rhoades concluded that this method was conservative and results in an over estimate of the LR. The computer simulation with the transient solute transport model showed no excessive salt accumulation during any period in the crop rotation. Under steady-state conditions, the LR would decrease from 0.13 to 0.11 when considering horizontal leaching and salt removal in tailwater and from 0.13 to 0.08 when considering salt precipitation. With salt precipitation and salt removal by tail water, the vertical LR would decrease to 0.07.

"For this study, we used a LR of 0.11 as estimated in 1994 by the TWG (1994). The volume of water required for leaching would be  $0.11/(1 - 0.11)$  or  $0.124 \times Et_{c(irr)}$ . Since the NRCE (2002) suggested that the change in Colorado River salinity was not considered, we adjusted the volume of leach water by the relative salinity of the Colorado River water at Imperial Dam as shown in Table 4.2. The salinity at Imperial Dam is modulated by flow through reservoirs on the Colorado River. The relative salinity had decreased from a 10-year average (1972-1982) value of near 1.0 following the high runoff in 1983-84. The relative salinity then increased back to the long-term trend by 1992-1993 and near the 1972-82 average by 1994. The long-term trend in Colorado River salinity at Imperial Dam indicates salinity is decreasing. The salinity level from 1998 through 2001 is significantly less than the 1972-82 average of 1.31 dS/m. The contribution of horizontal leaching and salt removal by tailwater is described under water balance calculations."

\* \* \*

"As discussed in the J-W (1997) report, use of 'Crop Leaching' as the closure or residual term exaggerates the crop-leaching component because that component is much smaller than the estimated tailwater component. Use of Crop Leaching as the closure term also tends to essentially result in constant on-farm irrigation efficiency because it is included in the numerator of the efficiency equation. Use of the crop-leaching component in the closure term does not reflect the relatively large variation in annual tailwater. When using tailwater as the closure term, the calculated crop leaching was 14.1% (the 1987 and 1988 values that were used in this report were adjusted to 12.4%) of irrigation water crop ET plus a small component of credit given for leaching by tailwater, so-called horizontal leaching. Rhoades (2002) derived a detailed procedure for adjusting vertical-leaching because of horizontal-leaching. In this study, the credit given for beneficial use of water for leaching was  $0.9 \times C_L \times ET_{c(irr)}$ , whether actually achieved or not, plus  $0.05 \times$  tailwater volume. This procedure gave results that were very similar to the

results obtained using more complex procedures with high tailwater values." (pages 12 through 14)